DGEN Aeropropulsion Research Turbofan (DART) Core/Combustor-Noise Infinite-Tube-Probe (ITP) Transfer Function

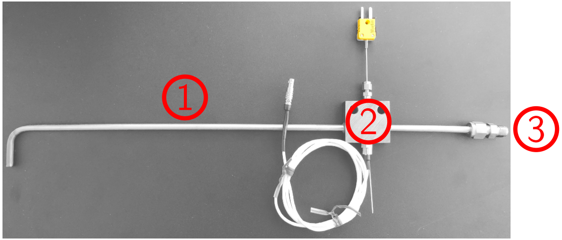
Devin K. Boyle
NASA Glenn Research Center, Cleveland, OH 44135

Acoustics Technical Working Group
Cleveland, OH, October 16–17, 2018

NASA Advanced Air Vehicles Program
Advanced Air Transport Technology Project
Aircraft Noise Reduction Subproject

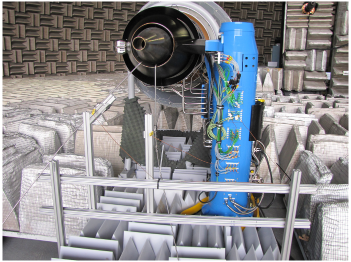
Introduction

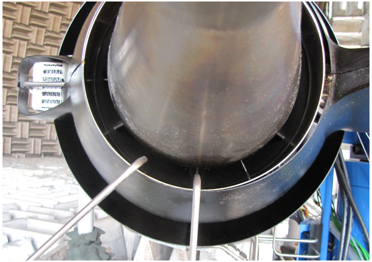
- Direct measurement of unsteady pressure in engine core is often impossible due to extreme temperature environment
- Remote measurement is necessary and it's done by using infinite-tube probe (ITP) configurations
  - ITP includes (1) sense line, (2) transducer tee and (3) "semi-infinite" coil
  - Discontinuities must be avoided, but some are inevitable (e.g. volume related to transducer in tee)



ITP Benchtop Test Objectives

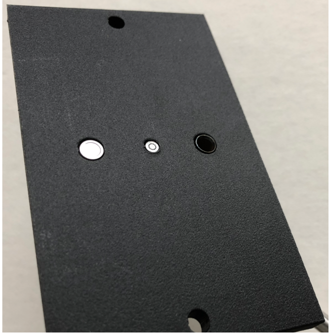
- Infinite-tube probe (ITP) benchtop testing
  - Determine frequency response (transfer) function relating remote measurement to pressure field at location of interest
  - Spectral magnitude loss and phase lag relative to a flush-mounted microphone
  - Perform parametric variations to understand effects and explore potential design improvements for current and future configurations

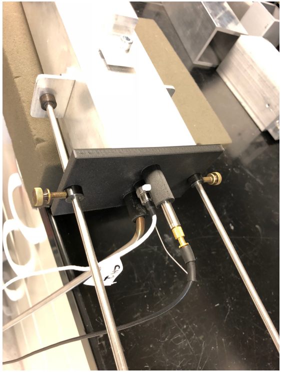




Experiment Setup

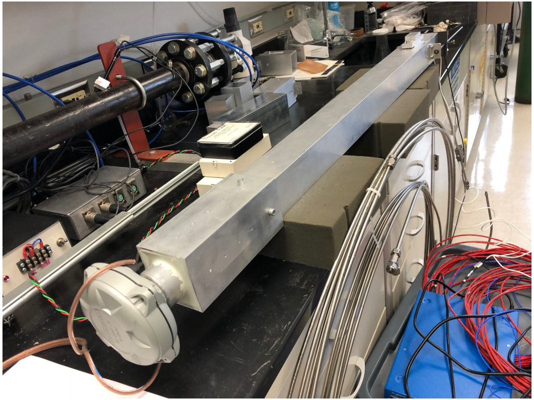
- Normal incidence tube (NIT) at GRC used with a modified termination (hard wall instead of test coupon)
- Integrated flush-mounted pressure-field microphone and Kulite differential unsteady pressure transducer
- ITP sense line installed alongside flush-mounted transducers





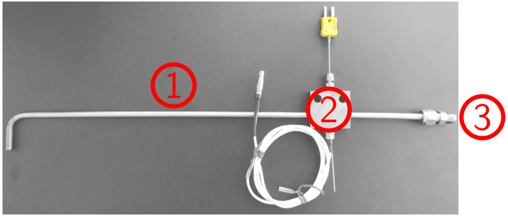
Setup Continued

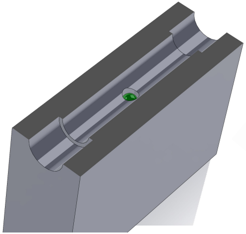
- NIT is 2 in$\times$2 in square impedance tube capable of producing tones in the range of 500-3000 Hz
- National Instruments hardware used with LabVIEW for data acquisition

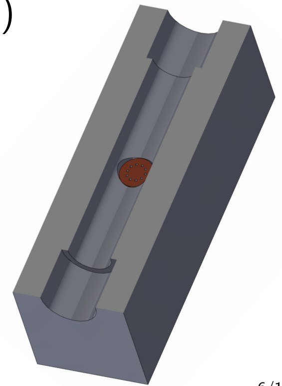


Configurations

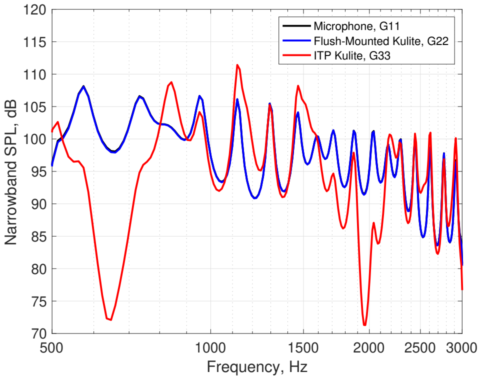
- Varying several physical parameters of the ITP configuration:
  - Infinite-line coil length (presented here-others remain)
  - Sense-line length
  - Tee design/ITP diameter
  - Introducing purge flow (nitrogen or shop air)
  - Thermocouple location
  - Thermal gradient within sense line

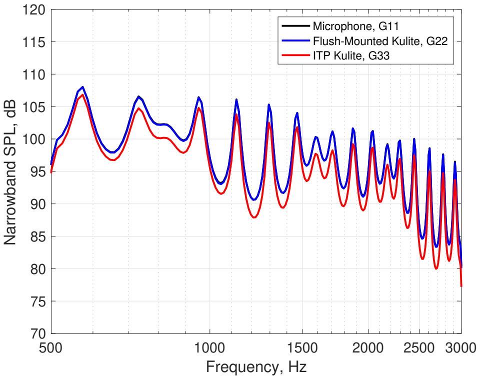






Auto-Spectra for All Sensors in Different Configs

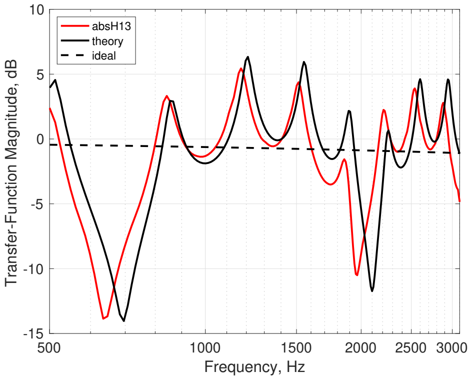


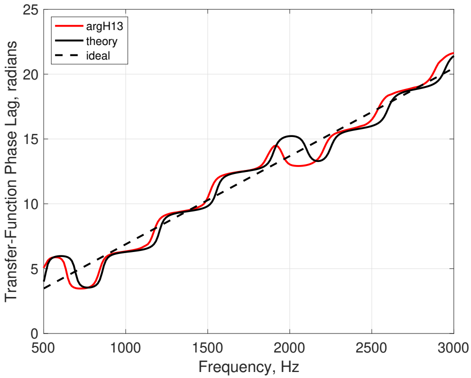


- ITP without semi-infinite coil
- Follows flush-mounted sensors poorly
- Both configurations capped

- ITP with semi-infinite coil
- Retains shape with slight attenuation

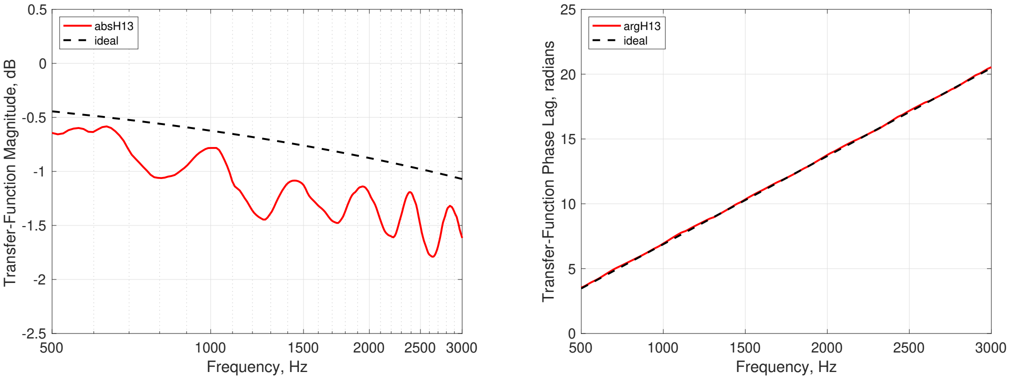
Transfer Function for Capped ITP Without Coil





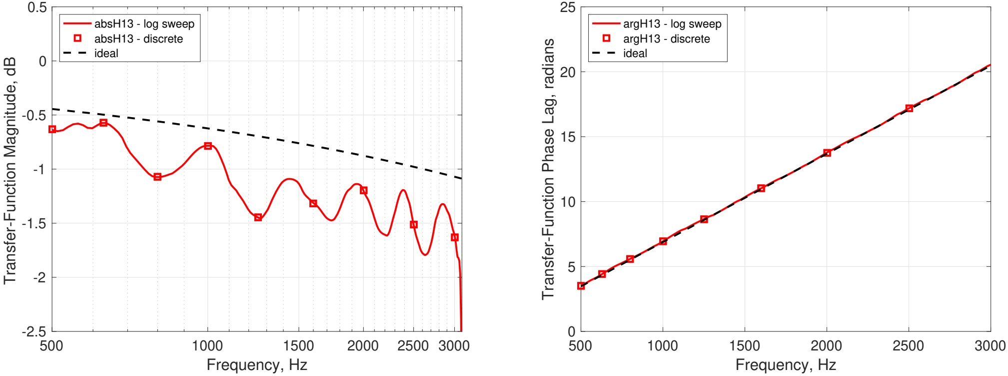
- ITP without semi-infinite coil
- Experimental results are same shape as theory, but poor representation at any given frequency
- Ideal case assumes infinite length beyond tee, i.e. complete attenuation of reflections

Transfer Function for Capped ITP With Coil



- ITP with semi-infinite coil and capped termination
- Magnitude retains shape with slight attenuation and exhibits undulations not represented in ideal case, which assumes no cavity volume at transducer tee
- Phase lag matches the ideal case well at all frequencies, indicating little dispersion

Transfer Function for Uncapped ITP With Coil



- ITP with semi-infinite coil and <u>un</u>capped termination
- Transfer function shape is identical to capped termination within experimental error
- Implies that length of "infinite-line" is adequate to completely attenuate pressure reflections from a finite line termination

Summary and Plan Forward

- Tested configurations of ITPs used in 2017 DART testing
- Overall, the ITP appears to match theoretical predictions reasonably well
- We plan to continue with parametric variations as discussed
- Intend to develop a representative theoretical curve for given configurations, thus avoiding need to test every one
- Collaboration with colleagues using ITPs, SIPs, ETCs is desired

Acknowledgements: We wish to thank AATT Aircraft Noise Reduction Project for support and funding as well as Chris Johnston for supporting our use of the NIT.

Questions?

Backup Slide: Equations

$$H(f) \equiv \frac{\hat{p}_1}{\hat{p}_0} = \mathrm{e}^{-\mathcal{H}L_S} \left[\frac{1 + Q\mathrm{e}^{-2\mathcal{H}(L_S + L_I)}}{1 + Q\mathrm{e}^{-2\mathcal{H}L_I}} + \frac{\gamma V_T}{n_T 2\pi r_o^2 \mathcal{H}} \left(\frac{\omega}{c_o} \right)^2 \frac{J_0(\alpha)}{J_2(\alpha)} \left(1 - \mathrm{e}^{-2\mathcal{H}L_S}\right) \right]^{-1} ,$$

$$\alpha = \mathrm{e}^{\mathrm{i}\pi/4} W \, ,$$

$$W = \sqrt{\omega r_o^2/\nu} \, ,$$

$$\mathcal{H}^2 = \left(\frac{\omega}{c_o} \right)^2 \frac{J_0(\alpha)}{J_2(\alpha)} \left[\gamma + (\gamma - 1) \frac{J_2(\alpha')}{J_0(\alpha')} \right] \, .$$